

# **SAVING LIVES THROUGH INVESTMENT IN SAFER ROADS: THE iRAP PARTNERSHIP**

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### **ABSTRACT**

By 2020 an estimated 1.8 million people will die annually on the world's road network. That is approaching 5,000 deaths every day. This scale of human tragedy is preventable. The international Road Assessment Program (iRAP) is active throughout the region, with programs completed or underway in Malaysia, Vietnam, China, Philippines, Singapore, Australia and New Zealand. The iRAP initiative brings together government and non-government agencies focussed on improving the safety of road infrastructure.

This paper provides an update on progress with RAP programs worldwide, including a number of case studies from countries where studies have been completed. The primary outcomes of the RAP initiative include:

- 'Star Rating' maps, which rate the safety of roads from the point of view of car occupants, motorcyclists, cyclists and pedestrians
- an estimate of the level of death and injury on each road based on current road conditions
- a recommended network-wide countermeasure program for consideration by local stakeholders and funding bodies
- an estimate of the number of lives that could potentially be saved, and the associated economic return on the investment, if a network-wide road safety improvement program were implemented.

### **1. INTRODUCTION**

iRAP was established to help tackle the devastating social and economic burden of road crashes. Without intervention, the number of deaths worldwide is projected to increase to some 1.8 million by 2020 [1]. The majority of this growth would occur in low-income and middle-income countries, which already suffer nine out of ten of the world's road deaths. Large as the problem is, making roads safe is by no means an insurmountable challenge; the requisite research, technology and expertise to save lives already exists.

Road safety engineering makes a direct contribution to the reduction of road death and injury. Well designed intersections, sufficient lane widths and good quality roadsides can significantly decrease the risk of a crash occurring and its severity. Footpaths and bicycle paths can substantially cut the risk that pedestrians and cyclists will be killed or injured in places where they mix with motorised vehicles.

By building on the work of Road Assessment Programmes in the developed world and with the expertise of leading road safety research agencies worldwide, including ARRB Group (Australia), TRL (United Kingdom) and the Midwest Research Institute (United States), iRAP has developed four globally-consistent protocols to assess and improve the safety of roads:

1. Risk Maps.
2. Performance Tracking.
3. Star Ratings.
4. Safer Roads Investment Plans.

The focus of this paper is on the third and fourth of these protocols; Star Ratings and Safer Roads Investment Plans. These two protocols are designed to be applied in low-income and middle-income countries where detailed, location-specific crash data is often not readily available. The approach of Star Ratings and subsequent development of Safer Roads Investment Plans represents a systematic approach to road infrastructure design and renewal, based on knowledge about where severe injuries are foreseeable.

## **2. PARTNERSHIPS**

Central to iRAP is a spirit of cooperation between organisations involved in making roads safe. iRAP works closely with automobile associations, governments, funding agencies, research institutes and other non-government organisations to ensure that projects benefit from broad support and diverse expertise. A key opening step in every iRAP project is an initial workshop with all stakeholders that aims to:

- develop a common understanding of the purpose of the iRAP project
- define clearly the relationship of iRAP to other aspects of road safety strategy in the country or region
- create strong support for the iRAP project at a political level and across all key government and non-government stakeholders.

Following this workshop, a steering committee is usually established which includes representatives of all key local stakeholders. At the completion of a project, iRAP welcomes the willingness of partner organisations to share the results in order that lessons learnt can be used across the rest of the world.

iRAP also encourages and supports several continuing post-project activities to ensure that genuine road safety gains are made and the capability of stakeholder organisations continues to grow. iRAP seeks to build a community of knowledge and a strong network of friendships between neighbouring iRAP projects. This allows ideas and experiences to be shared, and facilitates continuous improvement of RAP activities globally. Regional workshops are an important forum for this interaction: countries discuss their progress and results, and report back on implementation plans, research and evaluation exercises.

## **3. ROAD INSPECTIONS**

iRAP undertakes two types of detailed visual inspections of a road's design elements: drive-through and video-based. The type of inspection conducted depends on the availability of technology, the complexity of the road network and the degree to which a project is focused on building the capacity of road safety stakeholder organisations. In this paper, the focus is on video-based inspections since that is the type used in the Asia Pacific region to date. Video-based inspections are undertaken in two stages:

1. A specially equipped survey vehicle travels the iRAP network.
2. The video is later viewed by analysts, or raters, and assessed according to iRAP protocols.

The survey vehicle can record video images of a road (generally at intervals of 5–10 metres) using an array of cameras aligned to pick up panoramic views of the road (such as forward, side-left, side-right, and often rear). The main forward view is calibrated to allow measurements of key road design elements. The vehicles can drive along the road at normal speed while collecting this information.



**Figure 1.** A survey vehicle used in a recent iRAP project [2]

Following the completion of the video-based inspection, each road design element is measured and rated according to iRAP protocols. The rating team is generally comprised of local staff from stakeholder organisations. Raters undertake desktop inspections by conducting a virtual drive-through of the road network, looking at video frames at 100m intervals. The raters use specialised software to make accurate measurements of elements such as lane widths, shoulder widths and distance between the road edge and fixed hazards, such as trees and poles.

Prior to the video-rating process, the iRAP team can train raters who have been seconded to the project (see Figure 2). The training is typically conducted over five days, and includes detailed information on the programme, instruction on use of software, analysis of the inspection manual and test rating.



**Figure 2.** An iRAP video rating training session in Vietnam

A road's Star Rating is based on an inspection of design elements which are known from extensive research to influence the *likelihood* of crashes occurring and the *severity* of those crashes that do occur. The focus of the Star Ratings is on the design elements which influence the most common and severe types of crash on roads for car occupants, motorcyclists, bicyclists and pedestrians (this is discussed further in the following section). Each road design elements is assigned to a category by the raters. The delineation on a section of road, for example, is assigned to one of two categories, as shown below in Table 1.

**Table 1.** Rating categories for delineation

Delineation
Adequate
Poor

At the completion of the rating, it is possible to produce a detailed condition report that summarizes many roadway characteristics for the iRAP network. The report contains information such as the proportion of the network that has paved shoulders and number of locations that have adequate pedestrian crossings. This data forms the basis of Star Ratings.

## **4. ROAD PROTECTION SCORES**

Following the inspections, Road Protection Scores (RPS) are calculated for each 100m section of road using the iRAP online software [4]. A RPS is a measure of the likelihood of a crash occurring and its severity, based on an assessment of a road's design elements. The iRAP RPS was developed from a European Road Assessment Programme (EuroRAP) model designed to assess the protection afforded to car occupants by elements of the road in the event of a crash, and from an Australian Road Assessment Program (AusRAP) model that assesses both the protection afforded by the road to car occupants, and the likelihood of a crash occurring.

An important aspect of iRAP which shaped the development of the RPS is global consistency; the programme must be able to be applied in numerous countries, even when there is not detailed, location-specific crash data available. It is also designed to provide a foundation for predicting the number of deaths that is likely to occur on a road network. This forms the basis of fatality estimation and countermeasure generation.

### **4.1 Road Users**

Recognising that the mix of road users can vary between countries and that different road users have different infrastructure needs, a separate RPS is produced for the four groups that account for the majority of road use worldwide:

1. car occupants
2. motorcyclists
3. bicyclists
4. pedestrians.

A benefit of a comprehensive risk model that accounts for the majority of road users is that it expands the number of options for infrastructure improvement, thereby helping to ensure that the Safer Roads Investment Plans identify to save lives in the most cost-effective way.

### **4.2 Crash types**

The iRAP RPS is based on an assessment of the road design elements that correspond to the main types of crashes for each of the road users. In the case of car occupants and motorcyclists, the focus is on:

- run-off road crashes
- head-on crashes
- crashes at intersection.

In the case of bicyclists, the focus is on crashes that occur when a bicyclist is:

- travelling along a road
- crossing a road
- at a junction.

For pedestrians, the focus is:

- walking along the road
- crossing the road.

These crash and risk types were based on the collective experience of the global research team and in the knowledge that they provide a systematic framework to assess the majority of fatal crashes that occur – for example, in Europe, the three crash types listed account for four in five of deaths to car occupants on major rural roads.

### **4.3 Risk factors**

Several factors lead to a crash occurring and a person being killed or injured. There is invariably a chain of events leading to loss of control of a vehicle, a failure to correct and subsequent impacts with other vehicles, road-users or objects. The severity of injury resulting from the crash depends on the kinetic energy involved in the impact.

Road crash deaths and injuries can be mitigated by reducing the likelihood that a crash will occur. For example, the likelihood of serious crashes occurring at bends is higher than on straight sections of road. Hence, the likelihood that a crash will occur can be reduced by straightening bends. Even where a crash may be inevitable, the severity can be reduced by the provision of road design elements that protect road users by reducing the kinetic energy of the crash to a tolerable level.

Intervention to improve the protection afforded by roads may not reduce the number of crashes, but it will reduce the severity of injury.

Drawing on publicly available evidence and research, EuroRAP, AusRAP and subsequently, iRAP, has developed a series of factors that relate road design categories with the relative likelihood of crashes and their severity. These factors are then incorporated as variables into RPS equations. As an example, road signs, trees, ditches, and other elements can cause severe injury on impact, especially where speeds are high. However, well-sited safety barriers can be very effective in reducing injury, as illustrated below in Table 3. The table shows that the relative risk factor for safety barriers 1.75, while the factor for deep drainage ditches is almost three times higher, at 5.00. This reflects research shows that barriers help prevent death and injury by absorbing impact energies.

**Table 3.** Sample of car occupant risk factors for the condition of the roadsides and the protection level on high speed roads (>70km/h)

Category	Risk Factor
Safety barrier	1.75
Distance to rigid object 5-10m	3.80
Deep drainage ditches	5.00
Cliff	10.00

Figure 3 below illustrates a safety barrier (relatively low risk) and a steep embankment (relatively high risk).



*Safety barriers help reduce the kinetic energy of a run-off road crash for car occupants (risk factor = 1.75)*



*Steep embankments represent a severe roadside hazard for car occupants involved in a run-off road crash (risk factor = 5.00)*

**Figure 3.** Car occupant risk the protection from death or serious injury on a rural road <sup>1</sup>

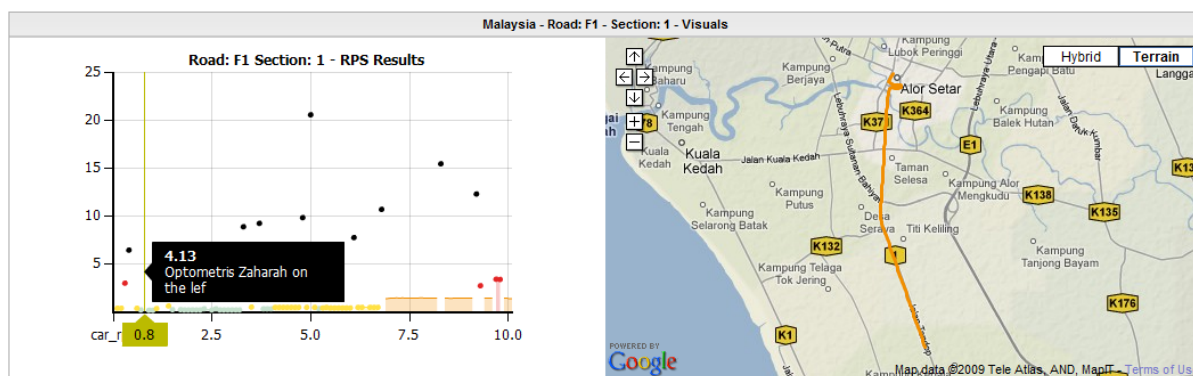
Research underpinning the likelihood and severity risk factors used in the iRAP model is cited throughout the iRAP Road Safety Toolkit (see [3] and [www.irap.org/Toolkit](http://www.irap.org/Toolkit)). Risk factors have been developed for each of the road user types, and for rural, semi-rural and urban roads.

## 5. STAR RATINGS

The RPS can be plotted in chart form for every road (for one example, see Figure 4). Along the horizontal axis is the distance in kilometres from the start of a road and on the vertical axis is the RPS. The chart highlights the fact that as a person moves along a road, the risk they face changes constantly as the road design elements vary. Such risk “worms” are automatically provided for specific roads by the iRAP software.

<sup>1</sup> Photo (above left) courtesy of Research Institute of Highways (RIOH), Beijing, China.

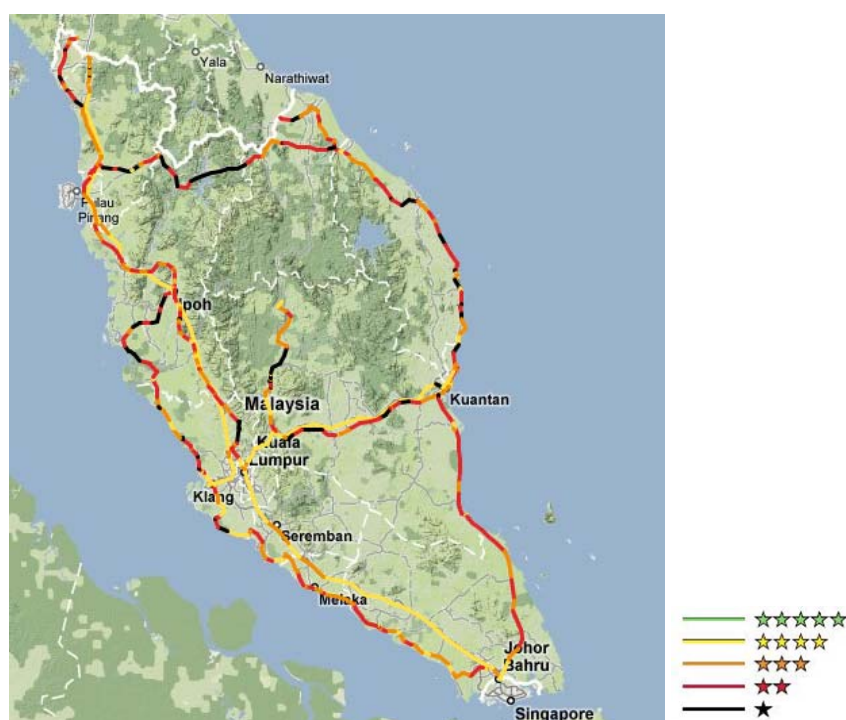




**Figure 4.** Car occupant Road Protection Scores (RPS) (Malaysia) [4]

In circumstances where highways are dual divided carriageway, a RPS is calculated for both directions. The scores are allocated to one of five Star Rating bands. The Star Rating system reflects the typical international practice of recognising the best performing category as 5-star and the worst as 1-star.<sup>2</sup> Star Ratings are produced on sections of road where there is demand for use by each of the road user types. In circumstances where, for example, bicycles do not use a particular section of road, then a bicycle Star Rating is not produced.

The Map in Figure 4 illustrates the car occupant Star Ratings for the iRAP network in Malaysia.



**Figure 4.** Car occupant Star Ratings in Malaysia [4]

## 6. SAFER ROADS INVESTMENT PLANS

Safer Roads Investment Plans involve the consideration of the condition of existing roads, estimates of the number of fatalities on existing roads and the application of proven engineering countermeasures where they are justified. The economic value of the countermeasures is assessed through an estimation of the likely crash or severity reduction outcomes, expressed as a monetary benefit. The costs of the treatment are calculated based on local authority data and a benefit cost

<sup>2</sup> Significant sensitivity testing was undertaken to determine how scores vary with changes in design elements. Star rating thresholds were set on the basis of this analysis.

ratio (BCR) is calculated. The countermeasures must pass a certain BCR criteria for inclusion in the final Safer Roads Investment Plan (e.g. BCR > 5).

## 6.1 Fatality estimation and crash cost

The iRAP model estimates fatalities by multiplying the RPS score by the traffic volume and the relevant fatality factor, as follows:

$$\sum_{i=1}^n \text{Car RPS} * \text{Car Traffic Volume} * \text{Car Fatality Factor} = \text{Car Occupant Fatalities}$$

To enable an understanding of the economic value of road safety countermeasures it is important to first have an indication of the existing crash problem. iRAP requires to key sets of data for this:

- total estimated fatalities on the road network being assessed
- total estimated fatalities by each road user group (e.g. vehicle occupants, motorcyclists, pedestrians and cyclists).

Since crash numbers across any road network are closely linked to the volume of traffic using the road and the speed vehicles are travelling, data on traffic volume, traffic mix and speed is sourced from available sources and included with the raw inventory data collected during the iRAP Inspections.

A 'fatality factor' is used to adjust the RPS and traffic volume data so that the total number of fatalities predicted closely matches the total estimated fatalities based on the available crash data. The factors capture the impact that other elements of a safe road system have on crash performance (e.g. helmet wearing, user behaviour and vehicle fleet condition). In a country where user behaviour and/or vehicle fleets are of a lower standard, then the fatality rates per kilometre of travel are often higher and the benefits associated with engineering improvements will often be greater. The fatality estimations are given as the number of fatalities (for a given mode) per km per year.

Using the estimation of fatalities on the road network, a crash cost is then determined. The iRAP publication *The True Cost of Road Crashes* [5] summarises the research into valuing life and the cost of a serious injury used by iRAP.

## 6.2 Countermeasure generation

The iRAP countermeasure generation module investigates the potential for approximately 70 proven engineering countermeasures to be applied systematically across the network where the need exists. For each countermeasure type, a series of conditions (or triggers) for where the treatment may be appropriate are defined. These triggers typically include a combination of:

- the Star Rating of the road section
- the condition of the road at that location
- the traffic volume and demand at the location.

In total there are approximately 200 trigger sets that highlight sections of road where certain countermeasures may improve safety. An example of the trigger set for delineation is provided in Figure 5 below.

For certain countermeasure types, a series of rules exist. These are used to ensure that the countermeasure recommendations align with typical engineering practice. For example:

- grade separated pedestrian crossings must be a minimum of 1 kilometre apart
- new signalised pedestrian crossings (non intersection facilities) must be a minimum of 600 metres apart
- additional lanes (overtaking lane or 2+1 cross section) must be required for a minimum length of 1 kilometre before they are confirmed viable.

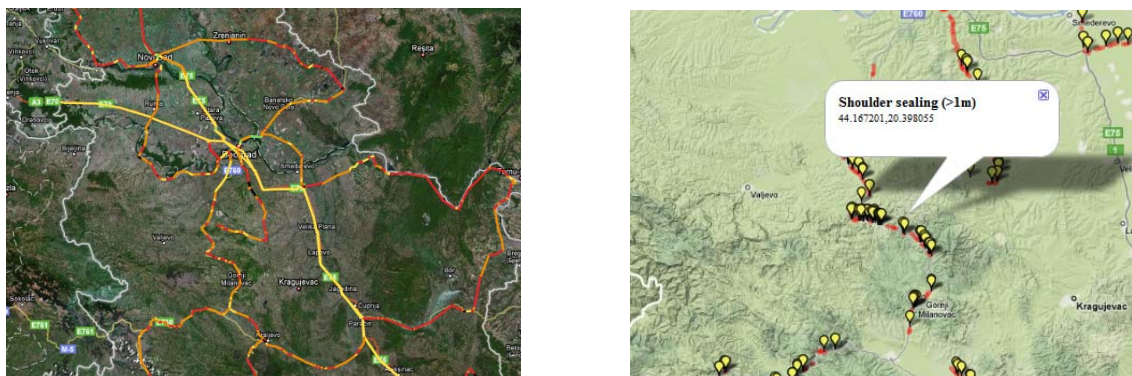
## Improve delineation [Countermeasure Triggers] Model 2.2

➕ Add a trigger set

<b>Trigger Set 1</b> <small>add trigger, duplicate, delete</small>	
Traffic flow	Greater than 0 <small>delete</small>
Delineation	Poor <small>delete</small>
Car RPS Star (Smoothed)	1-star or 2-stars or 3-stars or 4-stars <small>delete</small>
<b>Trigger Set 2</b> <small>add trigger, duplicate, delete</small>	
Traffic flow	Greater than 0 <small>delete</small>
Curvature	Moderate curvature <small>delete</small>
Delineation	Poor <small>delete</small>
Roadside severity	Deep drainage ditches or Steep fill embankment slopes or Distance to object 0-5 m or Distance to object 5-10 m
Car RPS Star (Smoothed)	5-stars <small>delete</small>
<b>Trigger Set 3</b> <small>add trigger, duplicate, delete</small>	
Traffic flow	Greater than 0 <small>delete</small>
Curvature	Sharp curve or Very sharp <small>delete</small>
Delineation	Poor <small>delete</small>
Car RPS Star (Smoothed)	5-stars <small>delete</small>
6 trigger sets in total for Improve Delineation	

**Figure 5.** Three of the six countermeasure trigger sets for delineation [4]

The proposed countermeasures are able to be plotted using iRAP software (see Figure 6).



**Figure 6.** Screenshot from iRAP software, illustrating location of proposed shoulder sealing on the iRAP network in Serbia [4]

### 6.3 Economic assessment

The next phase of the analysis is to determine the economic value of the treatment and ensure that it provides a responsible use of public money. The cost of the countermeasures is determined in consultation with the local road authority and planning experts. Generic treatment costs are estimated for urban, semi-urban and rural areas. Within each category there is provision for the likely complexity and upgrade cost at the location (low, medium and high upgrade cost). This is recorded by the rating team during the assessment of the road network.

For each improvement that is considered, there is an associated change in the condition of that attribute. For example, following the application of a delineation countermeasure, the associated code for the condition of delineation is updated from 'poor' to 'adequate' and the revised Road Protection Score (RPS) is calculated at the location. Fatalities are then estimated for the 'after' case and compared with the 'before' case. The calculation of car occupant fatalities (per year) is provided below as an example. Similar calculations are undertaken for each user group.

**Car Occupant Fatalities (before)**

$$= \sum_{i=1}^n \text{Car RPS (before)} \times \text{Car Traffic Volume} \times \text{Car Fatality Factor}$$



**Car Occupant Fatalities (after)**

$$= \sum_{i=1}^n \text{Car RPS (after)} \times \text{Car Traffic Volume} \times \text{Car Fatality Factor}$$

**Car Occupant Lives Saved (per year)**

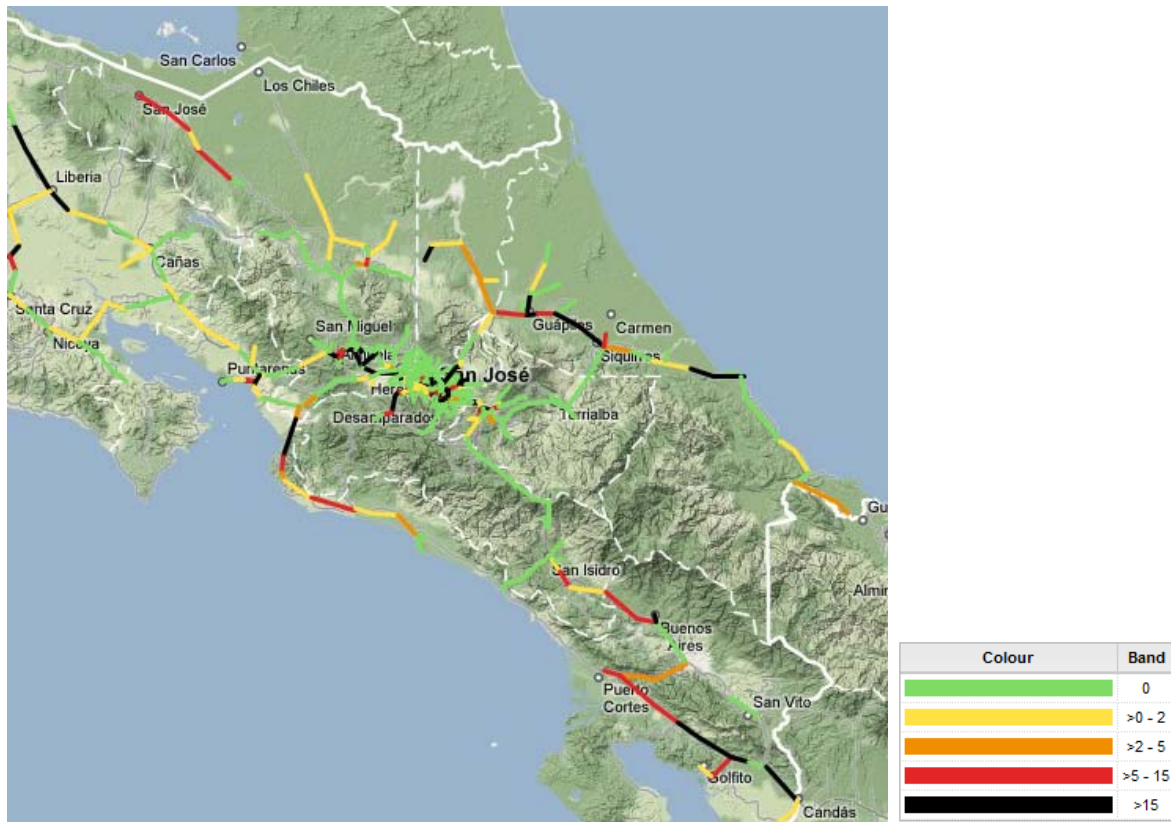
$$= \text{Car Occupant Fatalities (before)} - \text{Car Occupant Fatalities (after)}$$

**TOTAL Lives Saved (per year)**

$$= \text{Car Occupant Fatalities Saved} + \text{Motorcyclist Fatalities Saved} \\ + \text{Pedestrian Fatalities Saved} + \text{Bicycle Fatalities Saved}$$

$$\text{TOTAL Serious Injuries Saved (per year)} = 10 \times \text{TOTAL Lives Saved (per year)}$$

Using this information, the iRAP software is capable of producing maps that illustrate where deaths and injuries can be prevented across the network as a result of the countermeasures. Figure 7 illustrates the number of deaths and serious injuries that could be avoided during 20 years (per km) as a result of the proposed Safer Roads Investment Plan in Costa Rica.



**Figure 7.** Number of deaths and serious injuries avoided during 20 years (per km) in Costa Rica [6]

The economic benefit of the countermeasure is calculated by applying the assumptions discussed earlier:

**Annual Economic Benefit**

$$= (\text{TOTAL Lives Saved (per year)} \times 70 \times \text{GDP per capita}) \\ + (\text{TOTAL Serious Injuries Saved (per year)} \times 0.25 \times 70 \times \text{GDP per capita})$$

A benefit cost ratio is then calculated by comparing the economic costs and benefits. Following the assessment of the benefit cost ratio for each countermeasure, those treatments that meet the required BCR are confirmed as potential treatments (refer Section 5). For each 100 metre location the list of confirmed countermeasures is reviewed to ensure any treatments that duplicate an

impact on a particular road feature are appropriately addressed. This approach assumes that any new facilities are designed with safety as a key criterion. For example:

- if a grade separated pedestrian facility is feasible then that treatment will take precedence over all other pedestrian measures (e.g. refuge, signalised crossing)
- if a horizontal realignment is feasible then any treatments that are no longer relevant can be removed (e.g. curve delineation, shoulder widening)
- if a segregated motorcycle lane is feasible then any lower standard motorcycle lanes (e.g. an on-road motorcycle lane) can be removed from the program.

## 6.4 Affordability and implementation review

The initial Safer Roads Investment Plan completed for each country is typically based on a Benefit Cost Ratio (BCR) > 1.0. That is, all projects represent a positive return on investment. For many countries this criteria will result in a program that is not immediately affordable and optimisation of the investment plan must be undertaken. To facilitate this optimisation, the plan can be re-analysed for different BCR criteria. As the BCR criteria are raised, the associated total cost of the program is reduced. This can be continually refined until an affordable program is achieved (see for example, Table 3). The technique can also be utilised by Government and funding bodies to demonstrate how attractive and high return investment in safer roads can be. This can then be used as a tool to justify greater funding of road infrastructure.

**Table 3.** Safer Roads Investment Plan options for Serbia (\$US, 20 years) [2]

	Minimum BCR		
	1	3	5
Estimated cost to build and maintain	\$32	\$62	\$160
KSI saved	4,200	5,600	7,600
Value of safety benefit	\$360	\$477	\$652
Cost per KSI saved	\$0.008	\$0.011	\$0.021
Benefit cost ratio	11	8	4

KSI = killed and serious injuries. Lives and serious injuries saved are rounded.

Table 4 below provides an example of the top five countermeasures proposed in a Safer Roads Investment Plan. It shows that pedestrian crossings are proposed at 726 sites, at a cost of US\$9 million. It is estimated that these crossings have the potential to prevent more than 1,400 deaths and injuries and generate an economic benefit in excess of US\$170 million. That is, each dollar invested would generate \$19 in crash costs avoided.

**Table 4.** Safer Roads Investment Plan – top five countermeasures (US\$, 20 years)

Countermeasure type	Sites / length	Estimated cost	KSI saved	Value of safety benefit	Cost per KSI saved	BCR
Pedestrian crossing	726 sites	\$9	1,457	\$173	\$0.006	19
Shoulder widening	686km	\$13	1,292	\$153	\$0.01	12
Traffic calming	56km	\$2	386	\$46	\$0.004	26
Regulate roadside commercial activity	115km	\$1	160	\$19	\$0.009	13
Roadside safety – hazard removal	38km	\$1	48	\$6	\$0.018	7

KSI = killed and serious injuries

The Investment Plans provide a network level appreciation of viable countermeasure options and where they are located. It is recognised that the programs are based on video based assessment of road attributes and the use of generic network level costing and analysis. As with any engineering

program, all recommended countermeasures should be used as the starting point for detailed planning and implementation studies. This will ensure all local considerations are accounted for, and local designs are appropriate. The iRAP toolkit (see [3] and [www.irap.net/toolkit](http://www.irap.net/toolkit)) can also help road authority and consulting engineers assess the appropriate treatment for a location, and assess alternative options if necessary.

## **7. FUTURE DEVELOPMENTS**

Following the successful completion of pilot projects in South Africa, Malaysia, Costa Rica and Chile, and more recently, the completion of 'wave 2' projects in Nigeria, Kenya, Peru, Argentina and Serbia, important new programmes are underway. At time of writing, rating of more than 3,000km of roads was underway and more than 2,000km of roads were being assessed in China. Positive discussions are being held in numerous other countries in the Asia Pacific region, and important new agreements are being set in place in Africa, Eastern and Southern Europe and Latin America.

Throughout 2008, iRAP dedicated substantial efforts to continuous improvement and development of the knowledge base and technology underpinning its iRAP risk assessment and countermeasure programme models and online software. This included reviewing and revising the risk factors contained in the model on the basis of the results from the four pilot projects, and the addition of new countermeasures, such as segregated motorcycle and bicycle facilities and median crossing points. New functionality was added to the software, such as an on-screen report and map providing an estimate of numbers of deaths and serious injuries prevented per km over the 20 year analysis period. As additional projects in new countries are undertaken and new data becomes available, the models will continue to be developed to best reflect varying road networks, travel modes and local circumstances. Concurrent with these developments, iRAP set in place the structure for a Global Technical Committee to oversee and lead methodological research, development and quality assurance processes. This Committee will play an important role in coming years.

## **8. ACKNOWLEDGEMENTS**

The authors would like to acknowledge the outstanding global leadership and financial generosity of the FIA Foundation. iRAP's partnership with the World Bank Global Road Safety Facility has helped ensure that efforts have been focused on large scale interventions that can make a difference to casualties of global significance.

iRAP has benefited from the technical expertise of ARRB Group (Australia), TRL (United Kingdom) and the Midwest Research Institute (United States).

The authors also wish to acknowledge the outstanding efforts of the very many stakeholder organisations, which are too many to list here, which have contributed to iRAP worldwide.

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